Dynamic Channel Assignment Strategy for Uncoordinated OSA-Enabled WLAN

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Abstract

Efficient channel assignment is crucial for successful deployment and operation of IEEE 802.11-based WLANs. The use of Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard has increased significantly in the last years, especially for applications in both residential and commercial environments. Due to dense deployments of Wireless Local Area Networks (WLANS) the amount of available spectrum in ISM bands constitute a key limiting factor & causes congestion. A promising approach to alleviate ISM band congestion problems in highly dense WLAN scenarios consists of exploiting opportunistic spectrum access (OSA) to underutilized bands under a primary-secondary model. The developed distributed channel assignment algorithm will be valid for uncoordinated WLAN deployments where access points do not follow any specific planning and they could belong to different administrative domains. Unlike existing channel assignment schemes proposed for legacy WLANs, channel assignment mechanisms for OSA-enabled WLAN should address two distinguishing issues: channel prioritization and spectrum heterogeneity. So, objective of this proposed strategy for channel assignment is to reduce congestion in the crowded ISM band by allowing some access points (APs) to opportunistically operate in a primary band.

General Terms

Channel Assignment

Keywords
Channel allocation, IEEE 802.11, wireless Networks, OSA, WLAN, Distributed algorithm

1. Introduction
The use of Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard has increased significantly in the last years, especially for applications in both residential and commercial environments. With the increased popularity and deployment of Wireless Local Area Networks (WLANs), efficient management of wireless spectrum is becoming increasingly important. Dense deployments of Wireless Local Area Networks (WLANs) are rapidly increasing in urban zones, especially for providing Internet access within residential and office buildings by installing uncoordinated individual access points (AP). These deployments are leading to uncontrolled and excessive levels of interference in unlicensed bands that, ultimately, may turn into both an unpredictable degradation in network performance and unfairness among APs. In these scenarios, distributed channel assignment mechanisms constitute the main tool for reducing as much as possible the level of interference between neighboring WLANs in order not to impair individual network performance [1]. Thus far, WLAN distributed channel assignment problem in ISM bands has received a lot of attention in the research community [2], [3]. However, regardless of the ability of the different channel assignment algorithms to improve WLAN performance, the amount of available spectrum in ISM bands for WLAN use can still constitute a key limiting factor in dense deployments. Hence, the exploitation of additional bands for WLANs (e.g., licensed bands used opportunistically) can help improve the performance of such networks. Potential availability of unused portions of the radio spectrum (i.e., white spaces, WS) to be exploited opportunistically is supported by some recent studies [4]. As a result, major efforts are being conducted in both regulatory and standardization bodies to set out the regulatory and technical framework that will enable opportunistic spectrum access to WSs [5]. Hereafter, WLAN equipment able to use WSs in an opportunistic manner will be referred to as OSA-enabled WLAN. An uncoordinated deployment of OSA-enabled WLAN may also benefit from having appropriate channel assignment mechanisms to choose the operational channel in each AP among those available either in unlicensed ISM bands or in a given primary band

opportunistically exploited. Unlike existing channel assignment schemes proposed for legacy WLANs, channel assignment mechanisms for OSA-enabled WLAN should address two distinguishing issues: (1) channel prioritization, i.e. prioritization criteria other than interference conditions should be considered when choosing between an ISM or a primary channel; and (2) spectrum heterogeneity, i.e. channel availability might not be the same in each AP since it depends on the location and activity of the primary users (PUs). Over such a basis, the proposed distributed channel assignment mechanism that each AP would run asynchronously and that would not require any information exchange between APs (i.e., no coordination between APs). The proposed algorithm is designed to exploit both channel prioritization and spectrum heterogeneity. The proposed mechanism is aimed at keeping interference levels between APs below a certain interference threshold and, at the same time, keeping the utilization of the primary band as low as possible.

2. System Model:

2.1, Network Scenario

The network scenario which is considered consists of a set of individual APs (with their associated WLAN client stations) deployed in a limited geographical area. Each AP is expected to operate on an ISM channel or a channel available for opportunistic access in a licensed (primary) band. Licensee users of the primary band are referred to as primary users (PUs) while APs are secondary users (SUs) that can only use that band whenever the operation of PUs is not impaired. Note that channelization used by WLAN in the primary band (PB) could be different from that used by PUs. Fig. 1 illustrates the envisioned scenario where a dense deployment of OSA-enabled APs coexists with a primary system in the same geographical area.

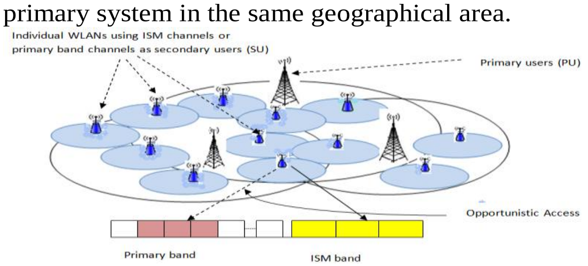

Figure 1: Network Scenario

2.2, Channel Assignment Constraints

Each AP must comply with certain constraints while channel allocation. These constraints are defined based on a metric called Interference Penalty (*IP*) that is used to quantify the interference level between a pair of individual WLANs. The *IP* metric is defined as follows:

$$IP(y^i,z^j) = \frac{[UA_z \cap IA_{y\rightarrow z}(\rho_{y\rightarrow z}^{i\ \ j})]}{UA_z} \qquad (1)$$

Where, UA→ Usage area
IA→ Interference area

ρ → Overlapping channel interference factor

$$\rho = \begin{cases} 1-|Fi-Fj| \times c & ; \rho \geq 0 \\ 0 & ; \text{otherwise} \end{cases} \qquad (2)$$

where *fi* and *fj* are the frequencies assigned to y^i and z^j respectively [6].

2.3, Condition on using primary channel:

Relying on the *IP* factor definition, the possibility of using a given primary channel in an SU is determined according to the accomplishment of the following two conditions: a) The usage area of a PU must not overlap with the interference area of a SU (i.e., $IP(SU^i,PU^j)=0$) Thus, since PUs have a priority use on the primary band, the SUs are not allowed to cause interference within the coverage range of the PUs, as shown in Fig. 2(a). b) The amount of overlapping between the usage area of a SU and the interference area of a PU must not exceed a certain threshold (*IPMAX*), (i.e. $IP(PU^i,SU^j) \leq IP_{MAX}$)

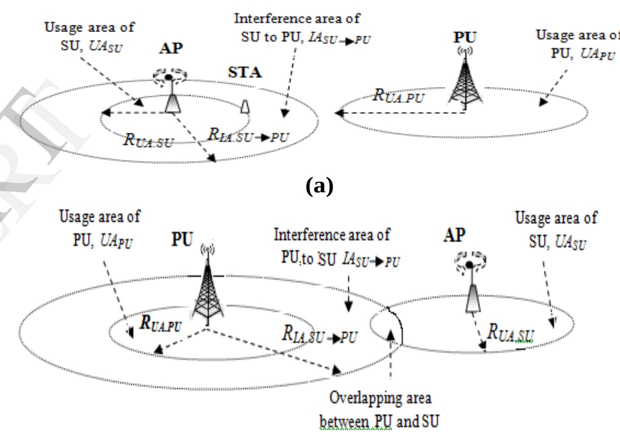

Figure 2: Interference conditions: a) From WLAN to PUs, b) From PU to WLANs.

2. Distributed channel assignment algorithm:

In this section, a distributed channel assignment mechanism that exploits both channel prioritization and spectrum heterogeneity is developed by means of a heuristic algorithm based on simulated annealing techniques. The algorithm is executed by each AP in a distributed manner and is only based on local information (i.e., no information exchange takes place between neighboring APs). The objective of the algorithm is to find a proper channel assignment for every AP so that the IP factor between any pair of APs $IP(ap_u^i, ap_v^j)$ is kept below a certain threshold IP_{MAX} and the number of APs using PB channels is minimized. The rationale behind pursuing a low usage of PB channels is that we are interested in finding a solution

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with low dependability on the presence of primary users.

3.1, Problem Formulation

The formulation of problem is done by mathematical way, in the following, $V= (ap_1, ap_2,\ldots\ldots ,ap_{ns})$ corresponds to the *ns* APs in the network scenario. The set of available channels for *apu* is defined as: $A(ap_u)=\{a_i|a_i \in \{0,1\}\ \forall\ 1 \le i \le C_T\}$, where a_i =i , if channel *i* is available at ap_u, $C_T=C_{ISM}+C_{PB}$, and C_{ISM} and C_{PB} are the number of available channels for WLAN operation in the ISM and PB bands, respectively. The Channel assigned to ap_u *is denoted as:* $C(ap_u) = \{i \mid 1 \le i \le C_T \wedge a_i = 1\}$. Two APs are considered to be neighbors if the *IP* factor calculated under co-channel conditions is greater than zero. Thus, the set of neighbors for *apu* is defined as:

$N(ap_u) = \{ap_v \mid \forall\ ap_v , \in V\ IP(ap^i_u , ap^i_v) > 0\}$. The maximum interference resulting at *apu* from its neighbors when channel *I* is used is computed by means of the following expression:

$$MIPap_u^{\ i} = \max_{\forall\, ap_v \in N(ap_u)} IP(ap_u^{\ i}, ap_v^{\ C(ap_v)})$$

If $MIPap_u^{\ i}$ is below the threshold *IPMAX*, then the channel *i* is considered as a feasible channel for the *apu*. In accordance with the above definitions a utility function $U(MIP^iap_u)$ is used to map $MIPap_u^{\ I}$ values to the preference given to channel *i* by *apu* when looking for an operational channel. The utility function is a decreasing function with respect to the amount of *MIP* so that the lower the *MIP* for a given channel, the higher the utility given to that the channel. In particular, a sigmoid function defined as follows is used in our analysis [7]:

$$U(MIP^iap_u) = \begin{cases} 1-(1-q).e^{s(MIPi_{apu}-IP_{MAX})} & ; MIPap_u^{\ i} \le IP_{MAX} \\ q.\ e^{-s(MIPi_{apu}-IP_{MAX})} & ; \text{Otherwise} \end{cases} \quad (3)$$

where *q* denotes the utility value when $MIP^iap_u = IP_{MAX}$, and *s* determines the slope of the utility function. The objective of the channel assignment problem is then set out to maximize the utility function. Hence, the channel assignment problem for each AP can be simply formulated as:

$$\text{Maximize } [U(MIP^iap_u)]$$

Subject to: ap_u only uses one channel at a time.

3.2, Algorithm Description

The algorithm is executed locally at each AP periodically and allows each one to select its operation channel, either from an ISM band or a primary band. The algorithm is made using the simulated annealing technique that uses a stochastic approach to direct the search of a channel assignment and targeted to maximize the utility function of the AP. Algorithm has four steps:

1. Initial channel assignment: At the beginning AP tries to find feasible channel as shown in figure 3.
2. Finding the candidate channel: When AP want to change channel then it find out all possible candidate channel and put them in list as shown in figure 4
3. Selection of candidate channel: AP select feasible channel from the list of candidate channel as shown in figure 5
4. Access to primary band : When AP doesn't get any channel from then it chooses channel from primary band as shown in figure 6

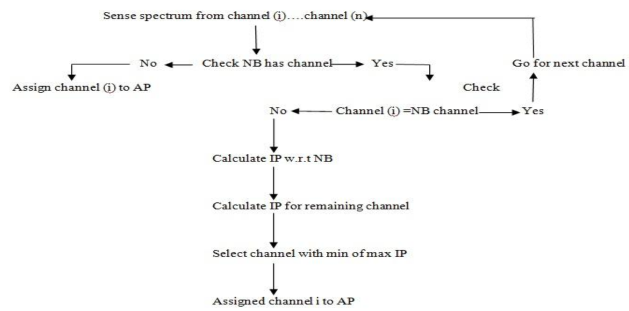

Figure 3: Initial channel assignment

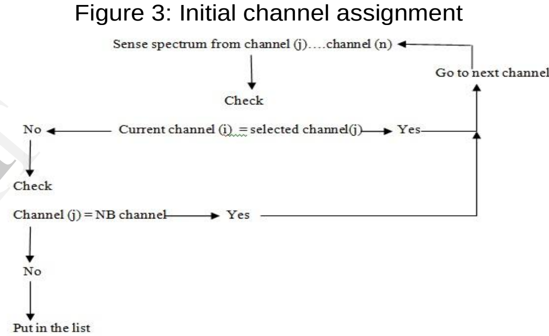

Figure 4: Finding the possible candidate channels

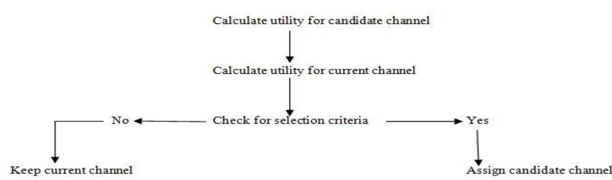

Figure 5: Selection of candidate channel

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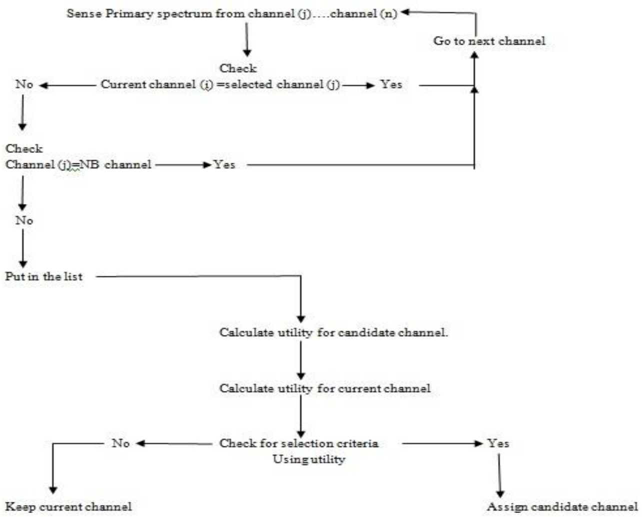

Figure 6: Getting access to primary band

4. Results

The proposed distributed algorithm evaluated the performance the ISM band with & without primary band for channel allocation in densely uncoordinated WLAN networks. This algorithm shows that as ISM band is constitute a key limiting factor, finding the feasible channel for AP opportunistically can help improve the performance of such networks. Figure 7 shows the channel assignment done with 50 access point. Additionally, for all evaluations, initial channel assignment is obtained by implementing the FF algorithm proposed in [8]. Figure 8 shows slope of utility function calculated during channel assignment.

5. Conclusion

This paper has proposed and evaluated the performance of a distributed algorithm designed for opportunistic channel allocation in densely uncoordinated WLAN scenarios. The algorithm has been shown to considerably increase the probability of finding feasible assignment solutions while achieving a low usage of the primary channels.

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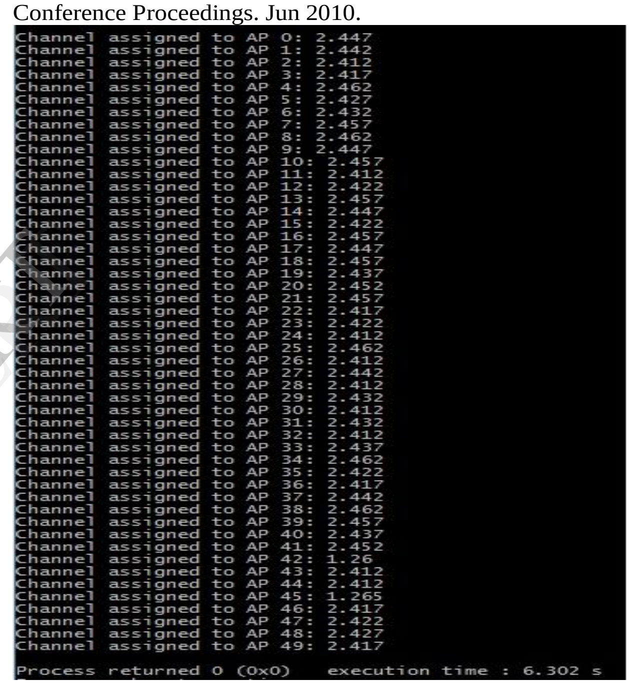

```
Channel assigned to AP 0: 2.447
Channel assigned to AP 1: 2.442
Channel assigned to AP 2: 2.412
Channel assigned to AP 3: 2.417
Channel assigned to AP 4: 2.462
Channel assigned to AP 5: 2.427
Channel assigned to AP 6: 2.432
Channel assigned to AP 7: 2.457
Channel assigned to AP 8: 2.462
Channel assigned to AP 9: 2.447
Channel assigned to AP 10: 2.457
Channel assigned to AP 11: 2.412
Channel assigned to AP 12: 2.422
Channel assigned to AP 13: 2.457
Channel assigned to AP 14: 2.447
Channel assigned to AP 15: 2.422
Channel assigned to AP 16: 2.457
Channel assigned to AP 17: 2.447
Channel assigned to AP 18: 2.457
Channel assigned to AP 19: 2.437
Channel assigned to AP 20: 2.452
Channel assigned to AP 21: 2.457
Channel assigned to AP 22: 2.417
Channel assigned to AP 23: 2.422
Channel assigned to AP 24: 2.412
Channel assigned to AP 25: 2.462
Channel assigned to AP 26: 2.412
Channel assigned to AP 27: 2.442
Channel assigned to AP 28: 2.412
Channel assigned to AP 29: 2.432
Channel assigned to AP 30: 2.412
Channel assigned to AP 31: 2.432
Channel assigned to AP 32: 2.412
Channel assigned to AP 33: 2.437
Channel assigned to AP 34: 2.462
Channel assigned to AP 35: 2.422
Channel assigned to AP 36: 2.417
Channel assigned to AP 37: 2.442
Channel assigned to AP 38: 2.462
Channel assigned to AP 39: 2.457
Channel assigned to AP 40: 2.437
Channel assigned to AP 41: 2.452
Channel assigned to AP 42: 1.26
Channel assigned to AP 43: 2.412
Channel assigned to AP 44: 2.412
Channel assigned to AP 45: 1.265
Channel assigned to AP 46: 2.417
Channel assigned to AP 47: 2.422
Channel assigned to AP 48: 2.427
Channel assigned to AP 49: 2.417

Process returned 0 (0x0)   execution time : 6.302 s
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Figure 7: Channel assigned in the network scenario of 50 AP

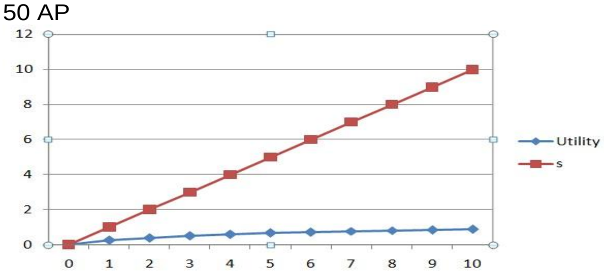

Figure 8: Slope of utility function